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INSTRUMENTATION OF SAMPLING AIRCRAFT FOR MEASUREMENT OF LAUNCH VEHICLE EFFLUENTS

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16. Abstract

An aircraft has been selected and instrumented to measure effluents emitted from large solid-propellant rockets during launch activities at the Air Force Eastern Test Range in Florida. The considerations involved in aircraft selection, sampling probes, and instrumentation are discussed with respect to obtaining valid airborne measurements. This paper includes discussions of the data acquisition system used, the instrument power system, and operational sampling procedures. Representative measurements obtained from an actual rocket launch monitoring activity are also presented.

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SUMMARY

An aircraft has been selected and instrumented to measure effluents emitted from large solid-propellant rockets during launch activities at the Air Force Eastern Test Range in Florida. The considerations involved in aircraft selection, sampling probes, and instrumentation are discussed with respect to obtaining valid airborne measurements. This paper includes discussions of the data acquisition system used, the instrument power system, and operational sampling procedures. Representative measurements obtained from an actual rocket launch monitoring activity are also presented.

INTRODUCTION

An aircraft has been instrumented to measure concentrations of effluents emitted from large solid propellant rockets during launch activities at the Air Force Eastern Test Range in Florida. These field measurements of effluents are being used to assess and refine diffusion models which serve to ascertain the environmental impact of NASA launch vehicles. The airborne measurements are being made in what is commonly referred to as the rocket exhaust "ground cloud" during its duffusion downwind from the launch pad. A light twin-engine fixed-wing aircraft was selected and instrumented by using the results of a parametric study of several potential airborne platforms and available instruments (ref. 1). The instruments selected are capable of measuring gaseous hydrogen chloride (HCl) and nitrogen oxides (NO_X and NO) and particulate effluents together with supporting flight parameters. All data are recorded with respect to launch time by a data acquisition system developed and qualified for airborne operation by the Langley Research Center (LaRC).

For a given launch monitoring activity, the aircraft is commercially chartered for a period of approximately 3 weeks. During this period, the aircraft is first brought into LaRC for instrument installation and checkout, then ferried to Florida for launch sampling, and finally returned to LaRC for instrument removal and subsequent return to the contractor until the next sampling activity. During sampling missions, the aircraft is manned by the pilot, the flight coordinator, and two instrument operators.

The aircraft was instrumented, certified, and is operated under the jurisdiction of the Federal Aviation Administration (FAA). Certification is in the Multiple Category, Standard and Restricted; the latter certification applies when the aircraft is instrumented for effluent measurements.

This paper presents discussions of (1) aircraft selection, (2) sampling probes, (3) instrument selection, (4) data acquisition system, and (5) instrument power system. Also included in this paper are representative data from a launch sampling.

SYMBOLS

D	cloud diameter, m
E_{SH}	self-heating effect, $^{o}C/mW$
l_{ref}	reference length (see fig. 3), m
M	Mach number
p	pressure, N/m^2
q	dynamic pressure, N/m^2
R	gas constant, J/kg-K
T	launch time
T_s	static air temperature, K
T_η	recovery temperature, K
V	voltage
V_l	local air velocity, m/sec
V_t	true airspeed, m/sec
V_∞	free-stream air velocity, m/sec
X,Y,Z	aircraft position coordinates

x	distance between sampling probe inlet and aircraft nose, m
η	recovery factor

Notation:

ac	alternating current
CBW	constant bandwidth
DAS	data acquisition system
dc	direct current
i.d.	inside diameter, m
NAA	neutron activation analysis
NEPH	nephelometer
o.d.	outside diameter
PADS	piloted aircraft data systems
PMT	photomultiplier tube
QCM	quartz crystal mass monitor
SEM	scanning electron microscopy

AIRCRAFT SELECTION

The primary consideration for the selection of an aircraft was to locate a position for the sampling inlets so that a collected air sample would not be altered by such things as engine exhaust or flow-field disturbance from the aircraft itself. Furthermore, for certain effluents (gaseous HCl and particles), the lines between the sampling inlets and effluent measuring instruments needed to be as short and as straight as possible. These considerations led to the selection of a twin-engine configuration with a large baggage compartment in the nose. With such a configuration, the inlets could be placed at the end of probes projecting out of the nose in the undisturbed free air with short and straight lines from the inlets to the sampling instruments installed in the nose baggage compartments.

Actual and required performance capabilities for the aircraft are listed in table I. A minimum flight speed (sampling speed) was based on the sample path time relative to the available response time of instruments in making the required measurements. Aircraft endurance was based on a required sampling period of $1\frac{1}{2}$-hr plus a $\frac{1}{2}$-hr fuel reserve. For the aircraft to be able to penetrate the ground exhaust cloud during its rise and at its subsequent stabilization height, aircraft rate-of-climb and ceiling requirements were established relative to the maximum expected rise rate and buoyancy level of the cloud. The flight crew required for a sampling mission, fuel, and sampling instrumentation weights were considered in establishing a useful load. Power requirements were set so that the total load (aircraft plus instruments) required for sampling flight could be provided by one alternator; the second alternator was used as a reserve in the event of the failure of the first alternator.

The final consideration in the selection of the aircraft was the disturbance of the effluents within the ground cloud created by the aircraft passing through the cloud to obtain the required measurements. Two aircraft disturbances were noted, that of the propellers and that of the wing-tip trailing vortices. Flow-field experience at LaRC had demonstrated that wing-tip vortices create a predominantly stronger disturbance than propellers. Consideration was also given to the fact that airplane weight has a significant influence on the strength of the vortices. (See ref. 2.) Therefore, the gross weight requirement for the aircraft was set as low as possible. The extent of disturbance was approximated by assuming that the size of each wing-tip vortex was one-half the wing span. Then the volume which a one-half wing span vortex cuts out of the center of the cloud upon aircraft passage, relative to the cloud volume (cloud assumed to be spherical in shape), could be determined. The results presented in figure 1 show that 0.07 percent of the cloud volume is disturbed. If 15 cloud passes are made during each sampling mission, the total cloud disturbance would be only approximately 1 percent of the cloud volume.

The actual aircraft selected with the sampling probes installed in the aircraft nose is shown in figure 2.

SAMPLING PROBES

After the aircraft nose had been selected as the air sampling inlet location, these considerations remained. (1) How far forward of the nose did the inlets have to be placed? (2) How far apart did the inlets have to be spaced?

Theoretically, the flow-field disturbance created by a body (in this case, the aircraft nose) passing through air extends to infinity. However, for this application, a disturbance value of $\frac{V_l}{V_\infty} = 0.95$ was assumed. With this value, the sampling flight speed, and the physical dimensions of the aircraft nose, the disturbance field was established by a LaRC computer program based on the flow-field solution of reference 3. From this analysis (see fig. 3), an inlet location 0.91 m forward of the nose was selected. Similarly, the flow-field disturbance of each inlet was determined with a resulting minimum spacing of 0.0127 m required.

To aline the sampling probes with the oncoming free stream, the aircraft was flown under actual sampling flight conditions, and the flight angle of attack was measured. The probes were set to account for this angle of attack (6.5^{o}) so that they would be parallel to the free stream during sampling.

INSTRUMENT SELECTION

Primary considerations in the selection of instruments were range, accuracy, minimum detectability, and response time. Response time was extremely important because measurement times within the rocket exhaust cloud could be as short as 20 sec. Since it was assumed that approximately 10 measurements along the sampling path would adequately define the effluent variation in the cloud, an instrument response time of 2 sec or less was established. At a sampling speed of 51 m/sec, a 2-sec response time provides a path resolution of 102 m.

Instrument size, weight, and operating power were also considered because of aircraft limitations. Where possible, instruments were selected that operated directly off the 28-V dc aircraft power to avoid the space, weight, and power conversion loss penalties associated with power inverters.

Required instrument measurements consist of (1) effluents (HCl, NO_x, NO, and aluminum oxide (Al_2O_3) particles), (2) meteorological conditions (temperature and relative humidity), and (3) flight conditions (aircraft speed, direction, altitude, and position). A list of the instruments selected together with their characteristics is presented in table II. Through the use of the cabin seat rails, the replacement nose cone, the nose baggage compartment flooring, and the inspection coverplates, the instrumentation is readily installed and removed without physically altering the aircraft permanently. Figures 4 and 5 show the instrumentation installed in the aircraft nose and cabin, respectively. Figure 6 shows the specific arrangement of the instrumentation onboard the aircraft. A description of the instrumentation is given in the following sections.

Hydrogen Chloride Detector

Because of the affinity that HCl has for the walls of sampling lines, especially if the gas is in a moist environment, an instrument was devised in which the sampling inlet tube is chemically treated with sodium bromate and sodium bromide to avoid wall absorption. Therefore, the sampling inlet was used as the aircraft sampling probe with the instrument sensor module placed in the aircraft nose so that the special inlet could be coupled directly to the module. To operate the sensor module remotely, a separate control module was installed in the instrument racks within the aircraft cabin. Both modules and the probe are shown in figure 7. The instrument, except for a longer inlet probe and repackaging, is identical to the HCl detector described and evaluated in reference 4.

A schematic diagram of the instrument designed to continuously monitor the HCl concentration in ambient air is shown in figure 8. The detection technique is based on a chemiluminescent reaction in which visible light is generated in an alkaline solution of 5-amino-2, 3-dihydro-1, 4-pathalazine-dione (luminol) during oxidation. The instrument contains a single reaction cell from which the visible light is monitored by a photomultiplier tube. The light output from the cell is proportional to the HCl concentration of the incoming sample stream. Prior to reaching the reaction cell, the sample stream is passed through the alumina sampling probe coated with sodium bromate and sodium bromide. This coating reacts with the HCl to produce hydrochlorite and hypobromite which catalyze the luminol oxidation.

The detector has reagent reservoirs that allow unattended operation up to 6 hr. The signal output is 0 to 5 V dc on any one of four manually or automatically selected scales: 0 to 0.2, 0 to 2, 0 to 20, or 0 to 200 parts per million by volume (ppm).

Before and after each launch sampling mission, the HCl detector is laboratory calibrated by using a bottle of approximately 100 ppm of HCl and a flow dilution system. In the field, before and after each sampling flight, a known liquid concentration of HCl is injected into the instrument, and the resulting instrument response is verified.

The sampling flow arrangement for this instrument is shown in figures 6 and 9. Since the gaseous HCl in the rocket exhaust cloud may combine with moisture droplets, provision of isokinetic flow to the sampling inlet became necessary. This was accomplished by sizing the probe inlet so that the pump in the sensor module would draw sampling air into the inlet at a velocity equal to the forward velocity of the aircraft.

Nitrogen Oxides Analyzer

The nitrogen oxides analyzer shown in figure 10 is a dual-channel chemiluminescent instrument that continually and simultaneously measures NO and NO_x $(NO + NO_2)$, then electronically subtracts the two measurements to give NO_2. A schematic diagram of this instrument is shown in figure 11. Filtered air is brought into the analyzer and separated into NO_x and NO channels. A molybdenum converter in the NO_x channel thermally converts the nitrogen oxides in the sample air to NO. The resulting NO is then mixed with ozone, and the mixture produces a chemiluminescent reaction whose emitted light is proportional to the NO_x concentration in the sample air. In the NO channel, the NO in the sample air is mixed directly with ozone. This mixture also produces a chemiluminescent reaction whose emitted light is proportional to the NO concentration in the sample air. A difference amplifier between the NO_x and NO channels provides a signal proportional to the NO_2 $\left(NO_x - NO\right)$. The nitrogen oxides analyzer is calibrated in the laboratory and field by using a bottle of approximately 100 ppm of NO and a portable calibration system containing both a flow dilution system and an ozone generator. The calibration procedure employed is described in reference 5.

The sampling arrangement for the nitrogen oxides analyzer is shown in figures 6 and 12. The sampling flow is obtained from a sampling probe designed to provide sampling air back to the aircraft cabin for any instruments located in the cabin. The end of this sampling line is connected to a discharge vent in the aircraft floor so that any unused sampling air can be dumped overboard. The sampling flow through the line is established by ram pressure at the inlet and by a slight negative discharge pressure. The nitrogen oxides analyzer sampling inlet is connected into the cabin sampling line with the required sampling airflow (0.00053 m^3/min) drawn off by a vacuum pump in the analyzer.

Integrating Nephelometer

A schematic diagram of the integrating nephelometer is shown in figure 13. The intake air is heated so that the relative humidity in the sample remains below 65 percent. As the air flows through the sampling volume, it is illuminated by a xenon flash lamp at a rate of eight flashes per second. The light reaching the photomultiplier tube is from the integrated scattering (over approximately 163°) by the aerosol particles in the sampling volume. The intensity of the scattered light as measured by the photomultiplier tube is proportional to the scattering coefficient of the aerosols. It has been shown empirically for a wide variety of aerosols that there is a nearly linear relationship between mass concentration and scattering coefficient (refs. 6 and 7). The maximum spread in the data from references 6 and 7 shows that the mass concentration can be estimated to within a factor of 2 from scattering coefficient measurements. Because of the complicated dependence of scattered intensity on particle size distribution and refractive index, there is a large uncertainty in mass concentration inferred from scattering measurements. However, light scattering techniques represent the state of the art for real-time continuous in situ measurements of aerosols. The integrating nephelometer is particularly suited for airborne effluent measurements because of the fast response time and high flow rate. Moreover, the integration over 163° minimizes the effect of angular dependence on scattering.

The sampling flow arrangement for the integrating nephelometer is shown in figures 6 and 14. The sampling probe was designed to provide an isokinetic flow of 0.14 m^3/min from the ram pressure at the inlet and a slightly negative discharge pressure. An analysis shows that for the size inlet used, the actual flow for a sampling speed of 51 m/sec would be 90 percent of 0.14 m^3/min.

Quartz Crystal Mass Monitor

The quartz crystal mass monitor (QCM) measures the particulate mass concentration of aerosols. The particles are impacted on the surface of a quartz crystal whose resonance frequency decreases as the particles accumulate. The rate of change in frequency is proportional to the mass concentration of the particles. The QCM, therefore, gives a real-time indication of mass concentration under rapidly varying conditions. This is a highly desirable feature for rocket exhaust cloud measurements.

In environments where there are high concentrations of particles, there is a rapid accumulation and buildup of particles on the crystal surface. This effect is illustrated in figure 15 where an accumulation of particles at one of the four impaction sites on the crystal is shown. As the particles pile on top of each other, the collection efficiency decreases, and the QCM response becomes nonlinear. Usually when this happens, the used crystal is replaced with a new one, and the sampling is continued. However, since the sensing part of the QCM is in the nose of the aircraft for this application, it is not practical to make in-flight crystal changes. Therefore, the instrument installation was arranged so that three separate sensors can be used sequentially; thus, the sampling time of the instrument is extended by a factor of 3. Also with the modified arrangement, the sensor is remote from the controls of the instrument. The three QCM sensors are located in the right nose section of the aircraft, and the controls are in the cabin as shown in figure 6.

In addition to the mass concentration measurements, the particles collected on the sensing crystals can be examined by scanning electron microscopy (SEM). This examination identifies the elemental constituents of the particles and in some cases gives an indication of the sizes and shapes of some particles. A more detailed description of the QCM is given in reference 8 as is a calibration procedure.

The sampling flow arrangement for the QCM is shown in figures 6 and 16. The intake air is provided by the probe that feeds the concentrator. (The concentrator is described in the following section.) The flow to each of the sensors is provided through one of the three small tubes leading to the sensing heads. The three small tubes were designed to provide an isokinetic flow of 0.0018 m^3/min to the sensors. This flow is obtained by the instrument pump and is directed through each sensing head by a three-way valve.

Concentrator

During each pass through the exhaust cloud, particles are collected on polycarbonate membrane filters for later weighing and elemental analysis. Ten filters are mounted in a carrousel arrangement in an aerosol concentrator (concentration ratio of 64:1). The intake to the concentrator follows two paths. One sixty-fourth of the air (volume) flows through a small slit into an inner chamber and finally through the collecting filter, while the remaining air flows around the inner chamber and out through the exhaust. (See fig. 17.) Because of their inertia, the particles pass through the slit with the smaller airflow volume and are collected on the filter. Thus, the particles in a large volume of air are concentrated in a small fraction (1/64) of that volume before being passed to the collecting filters. It should, however, be realized that the particles smaller than the 50-percent cut point are not efficiently collected. The 50-percent cut point for the concentrator (particle diameter at which the collection efficiency is 50 percent) is 1.1 μm. This means that particles smaller than 1.1 μm, as shown in figure 18, are not efficiently collected.

The filter wheel is rotated by the manual controls inside the aircraft cabin. Generally, one filter is exposed for one pass through the cloud. Neutron activation analysis (NAA) and scanning electron microscopy (SEM) are used to determine the elemental composition of the collected particles.

The sampling flow arrangement for the concentrator is shown in figures 6 and 19. Isokinetic flow at the sampling inlet was established by sizing the inlet so that the 0.28-m^3/min pump within the concentrator drew sampling air into the inlet at a velocity equal to the forward velocity of the aircraft.

Temperature Probe

A total temperature probe shown in figure 20 is mounted on the nose of the aircraft (fig. 6) to measure outside air temperatures. This instrument employs a resistance wire sensing element which is protected from particles in the airstream by a 90° bend in the sensing housing. The desired static air temperature T_s is related to the measured recovery temperature T_η by the equation

$$T_s = \frac{T_\eta - E_{SH}}{\left[1 + \eta(0.2M^2)\right]}$$

where M is Mach number. The recovery factor η for this probe is assumed to be unity at the airspeed and altitude flown for the sampling missions. The self-heating effect

E_{SH} is a significant factor at low airspeeds and altitudes, and for the sampling flight profiles, E_{SH} is of the order of 0.035° to 0.04° C per mW of electrical power dissipated in the probe. Recovery factor and self-heating effect are fully discussed in reference 9. Other effects such as relative humidity and evaporation of liquid water droplets are assumed to be negligible.

Dewpoint Sensor

Dewpoint is measured with an aircraft hygrometer system. Air is ducted through an externally mounted dewpoint probe on the nose of the aircraft (see fig. 6) into the dewpoint hygrometer chamber. (See fig. 21.) An optical sensing system controls the temperature of a thermoelectrically cooled mirror in the chamber to maintain a constant dew thickness on the mirror surface. The control and readout electronics are located in the aircraft cabin. (See fig. 6.) When the dew on the mirror is of constant thickness, it is in equilibrium with the partial pressure of the water vapor in the air sample. At this time, the temperature of the mirror is the measured dewpoint. Relative humidity is calculated during postflight data reduction by using the dewpoint and outside air temperature data and standard vapor pressure tables.

Airspeed and Altitude

Static and total pressures are sensed in the free stream with a probe connected by tubing to pressure transducers located in the cabin instrument rack. (See fig. 6.) This system is independent of the aircraft instruments. Altitude is measured with a barometric altimeter which has a linear output. True airspeed is calculated from the equation

$$V_t = \sqrt{\frac{2RqT_s}{p}}$$

where T_s is static air temperature in K, q is dynamic pressure (total pressure minus static pressure) in N/m^2, p is static pressure in N/m^2, and R is the gas constant in J/kg-K.

Response time of the pressure system to a step input is determined by measurement to be 0.06 sec and 0.01 sec for the static and differential pressure transducers, respectively, to reach the 1/e value of the pressure step. Corrections to the dynamic response caused by changes in airspeed and altitude are insignificant since sampling is performed at constant airspeed and altitude.

Heading

The compass auxiliary synchro output of the aircraft is converted to a signal voltage through a synchro demodulator. The signal voltage is calibrated with the compass cockpit indicator which relates the measurement to the ship's heading calibration. This calibration technique provides an accuracy of $\pm 2^{\circ}$.

Position

The aircraft is continually tracked during a sampling mission by NASA Wallops Flight Center mobile AN/MPS-19 radar unit. To facilitate tracking, an onboard S-band beacon and antenna are located on the bottom of the aircraft fuselage just aft of the nose wheel housing. The tracking data are used to establish the distance of the cloud from the launch pad for each measurement pass by the sampling aircraft.

Time-Code Generator

For correlation purposes, all sampling and supporting data are referenced to universal time. Onboard the aircraft, a portable battery-operated (6 hr useful life) time-code generator is coupled with the data acquisition system to provide continually a time reference for the recorded sampling measurements. Prior to each sampling flight, the time-code generator is synchronized electronically with range time.

DATA ACQUISITION SYSTEM

The data acquisition system (DAS) is a constant bandwidth FM (CBW-FM) encoding subsystem with onboard magnetic tape data storage. Components of this system were taken from the LaRC inventory of piloted aircraft data systems (PADS) hardware which was designed and constructed at LaRC specifically for airborne application. PADS is a modular system and can be expanded to meet a wide range of measurement requirements. As the diagram of figure 22 indicates, all data signals are fed to the signal conditioning unit where they are brought to standard voltage levels and proper impedances. The signal conditioning unit also provides the means for introducing preflight calibration levels in lieu of data signals to the data acquisition system for use in the data reduction process. The CBW-FM subsystem has four multiplexes of 5 voltage controlled oscillators each, for a total of 20 data channels. Frequency response is 0 to 400 Hz at a deviation ratio of 5, and within a multiplex, the relative phase correlation between channels is 5°. The multiplexes are directly recorded on four tracks of magnetic tape run at 0.1905 m/sec which provides a data storage capacity of approximately 2 hr. Onboard time (NASA 36-bit) and voiced comments from the flight crew are recorded on two additional tracks. The data tapes are returned to LaRC for playback, editing, and data reduction. Through the use of a calibrated signal technique, the data acquisition system provides a measurement accuracy (not including sensors) better than 1 percent of full scale in this application.

INSTRUMENT POWER SYSTEM

The instrument power system shown schematically in figure 23 is designed to provide both dc and ac power from either the aircraft or the ground source and to distribute it to various research instruments onboard the aircraft. The aircraft power source is two 100-A 28-V dc alternators (one on each engine) which are electrically coupled to share the electrical load imposed upon them. Instrument power requirements listed in table III show the dc amperage load that each instrument imposes upon the aircraft power source. These loads account for conversion losses when converted from dc to ac. Total power load of 94.7 A was purposely held below one alternator capacity of 100 A so that the failure of one alternator would not impair total sampling capability. Aircraft instrument panel ammeters allow the pilot to monitor the total load on each alternator, and a master control switch in the cockpit allows the pilot to remove all instrument power in an emergency situation. Circuit breakers provide the required protection for the aircraft power system in case of an electrical malfunction of the sampling instrumentation.

OPERATIONAL SAMPLING PROCEDURES

For each launch sampling activity, the aircraft is operated from the NASA flight hangar at Patrick Air Force Base in Florida. Twenty minutes before launch, the aircraft is airborne in a racetrack holding pattern at an altitude of approximately 1000 m west of the Kennedy Space Center Vertical Assembly Building. Just prior to launch, the aircraft is directed under Air Force Eastern Test Range radar vector control toward the launch pad area, crosses the safety boundary lines at T + 2 min, and commences exhaust cloud penetrations around T + 4 min. Sampling penetrations as shown in figure 24 are made in straight level flights through the exhaust cloud centroid (visually determined by the pilot) alternately in a downwind and crosswind direction. In some instances, the penetrations are made at several incremental altitudes below the cloud centroid. Sampling penetrations continue until the cloud cannot be seen visually (usually around 1 hr after launch). Instrumentation operational status is verified in flight before, during, and after each sampling flight. Pertinent real-time information during the sampling flight is voice recorded into the DAS for later playback.

REPRESENTATIVE DATA

Aircraft sampling data from a Titan IIIC launch at the Air Force Eastern Test Range in Florida are shown in figure 25. Variations of the gaseous (HCl and NO_X) and particulate effluents with time as the aircraft passes through the centroid of the exhaust cloud are presented. From these measurements, data such as cloud rise, size, and movement, together with peak effluent concentrations or dosages, are obtained for comparison with predictive models used in launch vehicle environmental impact studies. For example, using the responsive nephelometer instrument, cloud size is determined from time in cloud (T = 7.53 to 8.01 min after launch from fig. 25) and aircraft sampling speed. Cloud rise (altitude plotted against time) and movement (heading and location from pad) are determined from aircraft radar position at the midpoint time of the nephelometer response. Peak effluent concentrations are determined from maximum effluent instrument readings, and dosage is determined from the area under the data curves. (See NO_X data of fig. 25.)

CONCLUDING REMARKS

A twin-engine fixed-wing aircraft has been selected and instrumented to obtain in situ measurements of effluents emitted from large solid-propellant rockets during launch activities at the Air Force Eastern Test Range in Florida. The measurements, made in what is commonly called the rocket exhaust "ground cloud," are being applied to assess and refine predictive models used in ascertaining the environmental impact of NASA launch vehicles. Considerations for the selection of the aircraft, design and positioning of sampling probes, and effluent measuring instrumentation have been discussed in detail. The instruments selected provided the capability to measure gaseous (hydrogen chloride and nitrogen oxides) and particulate effluents together with supporting flight parameters. Sampling procedures and representative launch monitoring data gathered by the sampling aircraft have also been presented and briefly discussed.

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TABLE I.- SAMPLING AIRCRAFT PERFORMANCE CAPABILITY

	Actual	Required
Minimum flight speed	43 m/sec	51 m/sec
Endurance	4.3 hr	2 hr
Rate of climb	491 m/min	366 m/min
Service ceiling	7980 m	3048 m
Useful load	1160 kg	907 kg
Total electrical power	200 A, 28 V dc	200 A, 28 V dc
Maximum gross weight	2858 kg	2948 kg

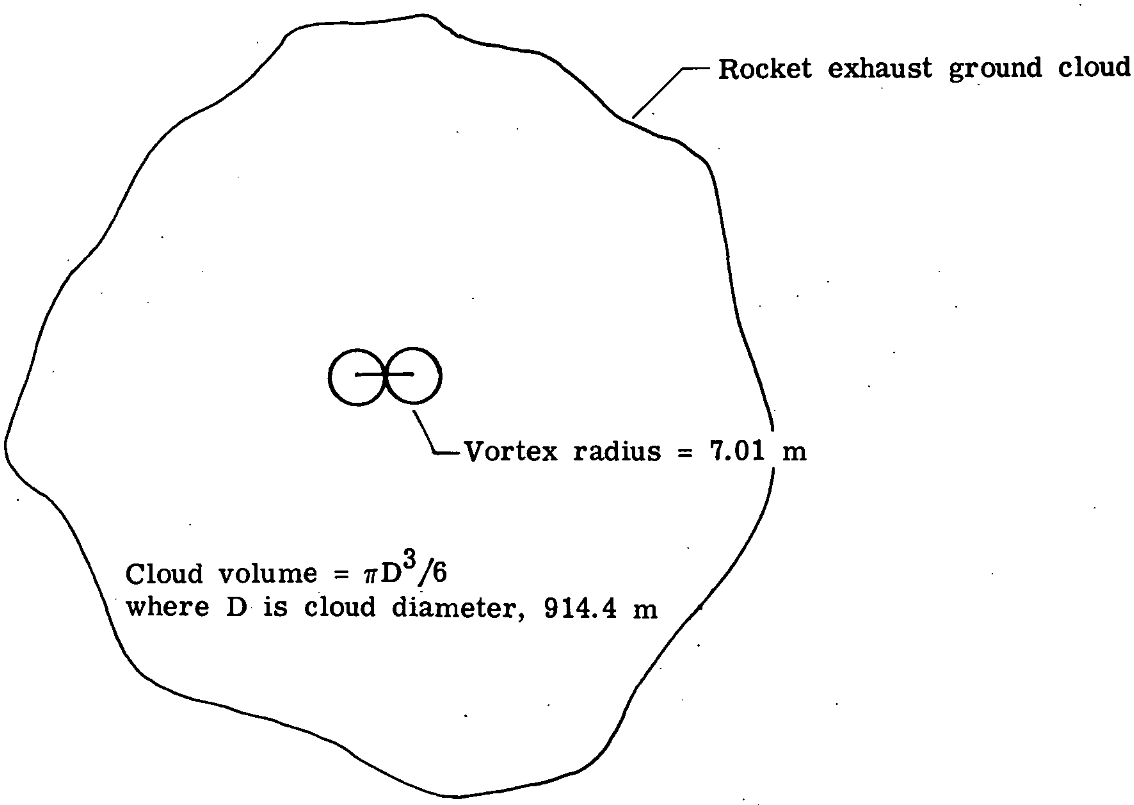
TABLE II. - SAMPLING AIRCRAFT INSTRUMENT CHARACTERISTICS

Categories measured	Instrument	Measurement	Technique	Range	Accuracy	Minimum detectability	Response 90 percent F.S.
Effluents	Hydrogen chloride detector	HCl	Chemiluminescent	0 to 2, 0 to 20, 0 to 200 ppm	±5 percent	0.1 ppm	1 sec
	Nitrogen oxides analyzer	NO, NO_2, NO_x	Chemiluminescent	0 to 0.2, 0 to 0.5, 0 to 1, 0 to 2, 0 to 5 ppm	±1 percent	2 ppb	1 sec
	Integrating nephelometer	Scattering coefficient	Light scattering	0 to 3800 $\mu g/m^3$	≈10 percent	9 $\mu g/m^3$	0.2 sec
	Quartz crystal mass monitor	Mass concentration	Frequency mass	0 to 2000 $\mu g/m^3$	≈ 3 percent	3 $\mu g/m^3$	2 sec
	Concentrator (filter)	Mass	Inertial impaction	----------	----------	----------	----------
Supporting meteorological and flight conditions	Total temperature probe	Air temperature	Resistance thermometer	±30° C	±0.5° C	<0.1° C	<1 sec
	Hygrometer	Dewpoint temperature	Cooled mirror	±100° C	±0.5° C	<0.1° C	NA[a]
	Pressure transducer	Pressure	Differential pressure	0 to 5171 N/m^2	±10.34 N/m^2	<6.89 N/m^2	<1 sec
	Barometric altimeter	Pressure	Absolute pressure	1016.95 to 468.75 N/m^2	±15 N/m^2	<1.5 N/m^2	<1 sec
	Compass	Heading	Synchro demodulator	0° to 360°	±2°	<1°	NA[a]
	S-band beacon	X, Y, and Z	----------	220-W peak power	----------	----------	----------
	Time-code generator	Time	Crystal oscillator	6 hr	±0.25 sec	0.001 sec	----------

[a]Not applicable.

TABLE III.- INSTRUMENTATION POWER REQUIREMENTS IN AMPERES BASED ON 28 V dc

Hydrogen chloride detector	3
Nitrogen oxides analyzer	19
Quartz crystal monitor	1
Nephelometer	5
Concentrator	24
Temperature/dewpoint instrument	9.6
Compass heading	0.8
S-band beacon	0.5
Data acquisition system	6.8
Total instrumentation electrical load	69.7
Aircraft operational load	25.0
Total aircraft load during sampling operations	94.7



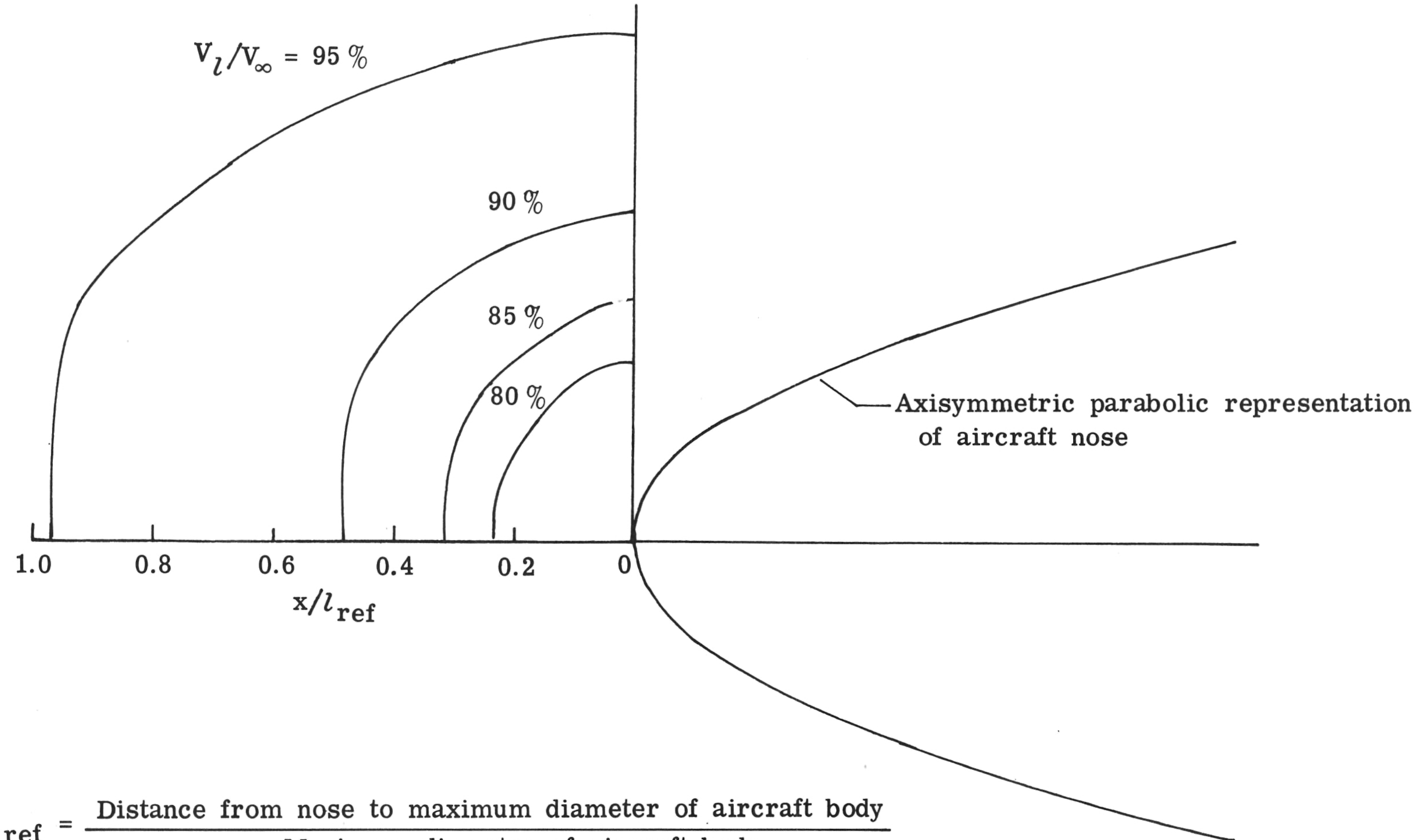
$$\frac{\text{Vortex volume}}{\text{Cloud volume}} = \frac{2\ \pi\ (\text{Vortex radius})^2 \times D}{\pi D^3/6} = 0.0007$$

or 0.07 % per pass through cloud

Figure 1.- Aircraft cloud disturbance.

L-74-7971

Figure 2.- Overall view of sampling aircraft.



$$l_{ref} = \frac{\text{Distance from nose to maximum diameter of aircraft body}}{\text{Maximum diameter of aircraft body}}$$

Figure 3.- Velocity distribution for idealized aircraft nose.

L-74-7980

Figure 4.- Installation of instrumentation in aircraft nose baggage compartment.

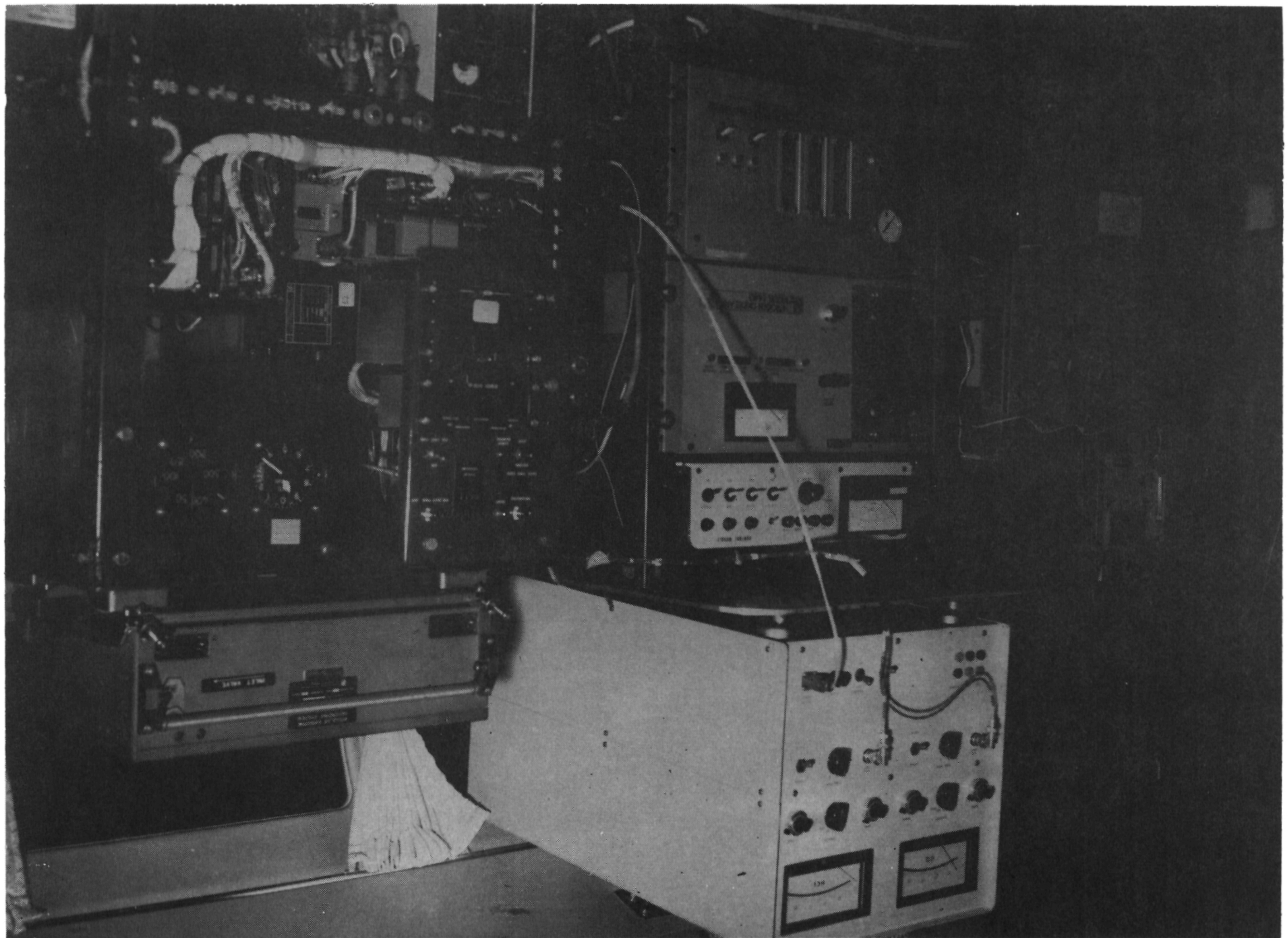


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Figure 5.- Installation of instrumentation in aircraft cabin.

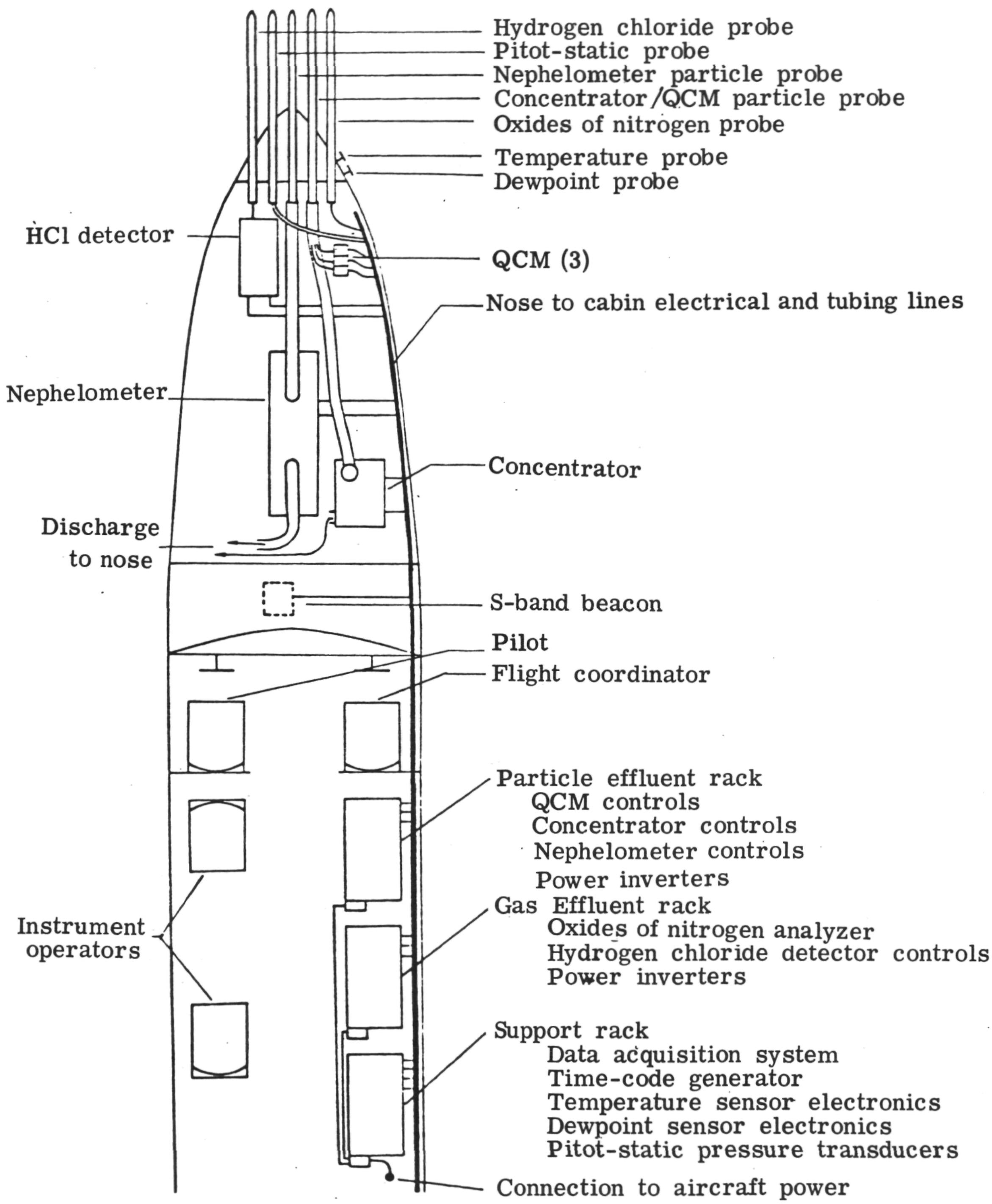

Figure 6.- Arrangement of instruments onboard aircraft.

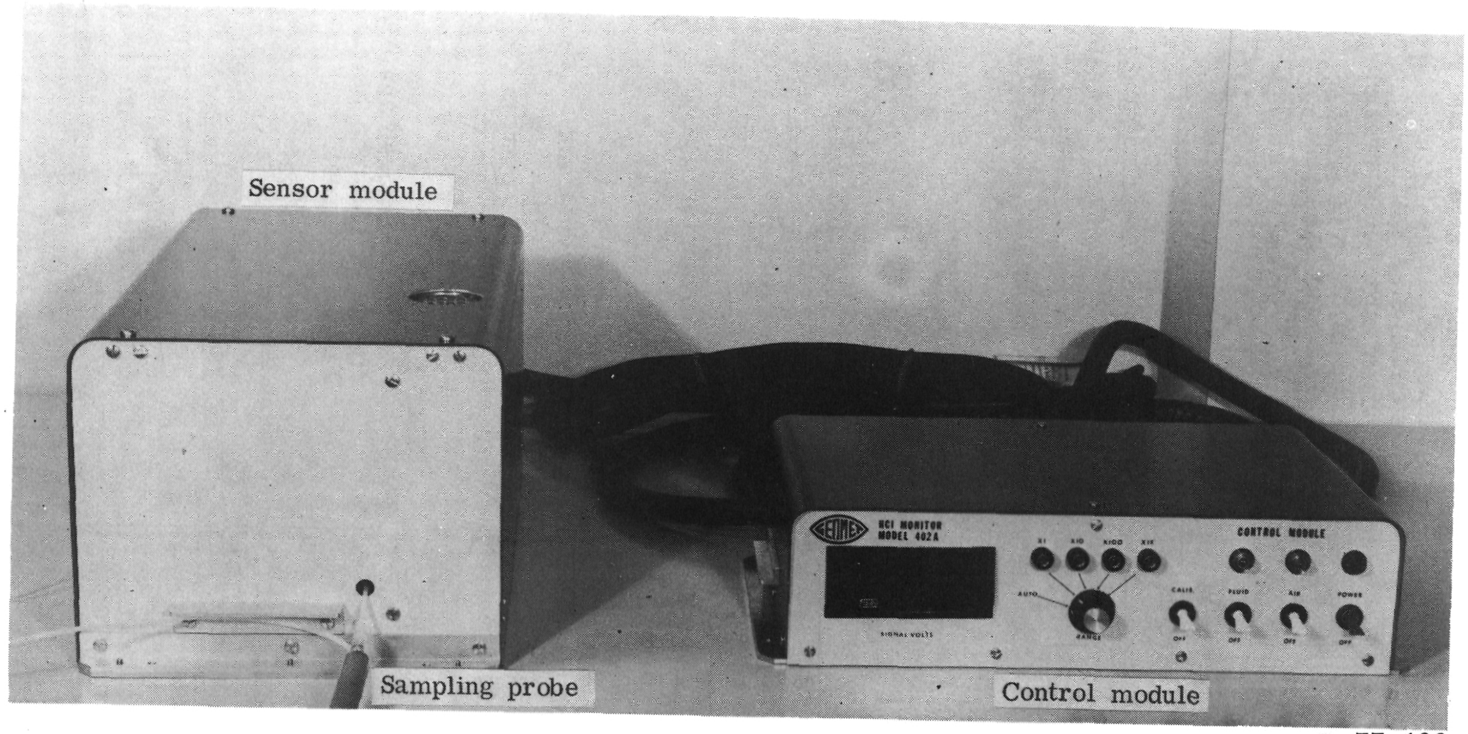

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Figure 7.- Hydrogen chloride detector.

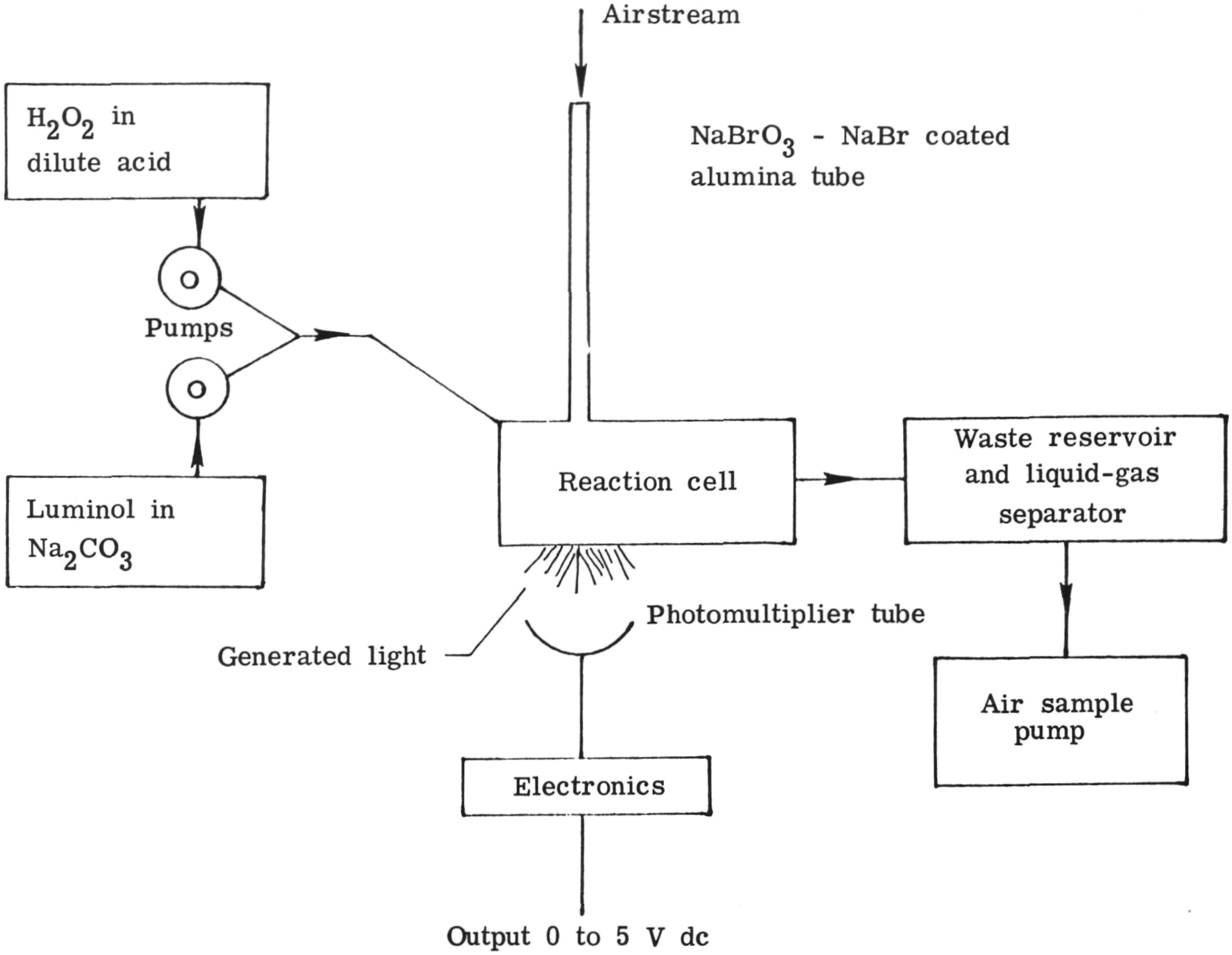

Figure 8.- Schematic diagram of HCl detector.

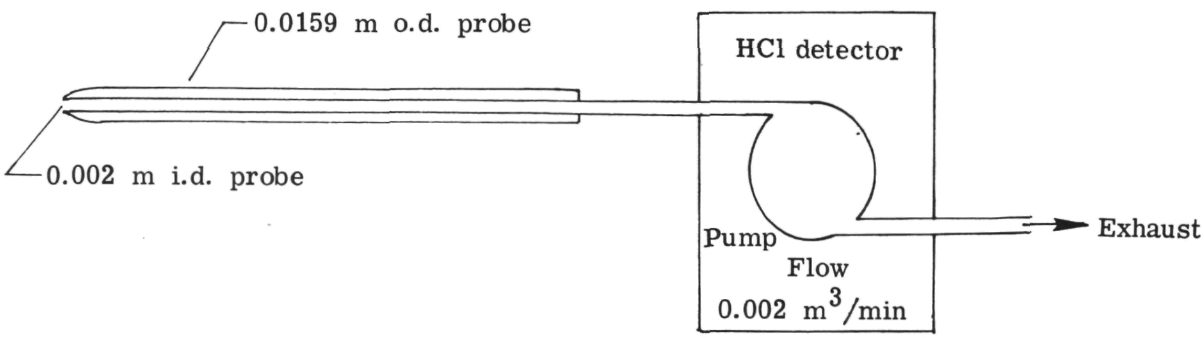

Figure 9.- HCl detector sampling flow arrangement.

L-77-194

Figure 10.- Oxides of nitrogen analyzer.

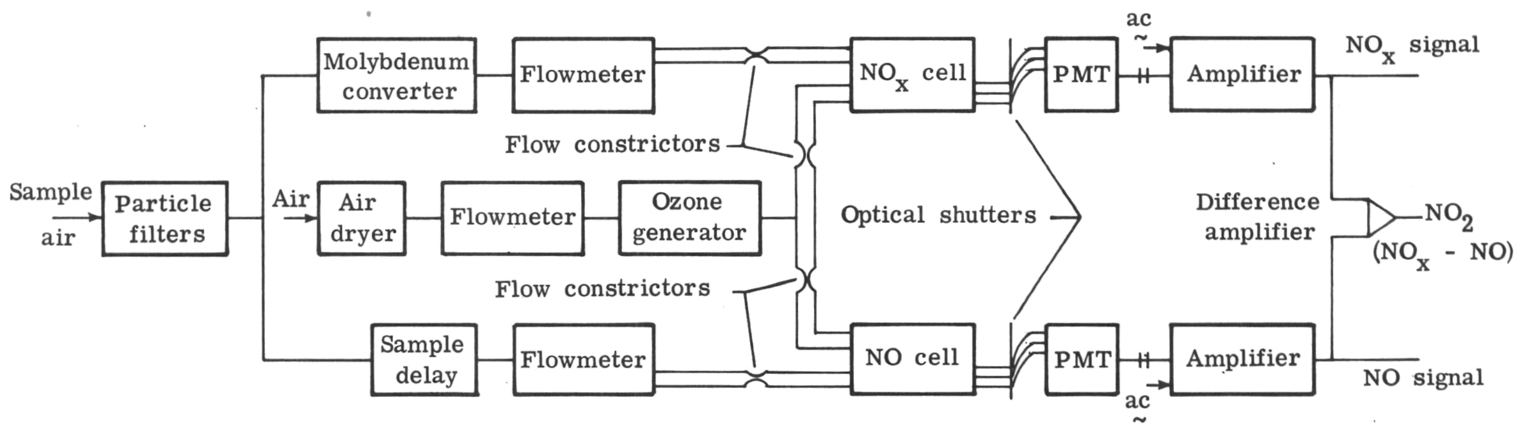

Figure 11.- Schematic diagram of oxides of nitrogen analyzer.

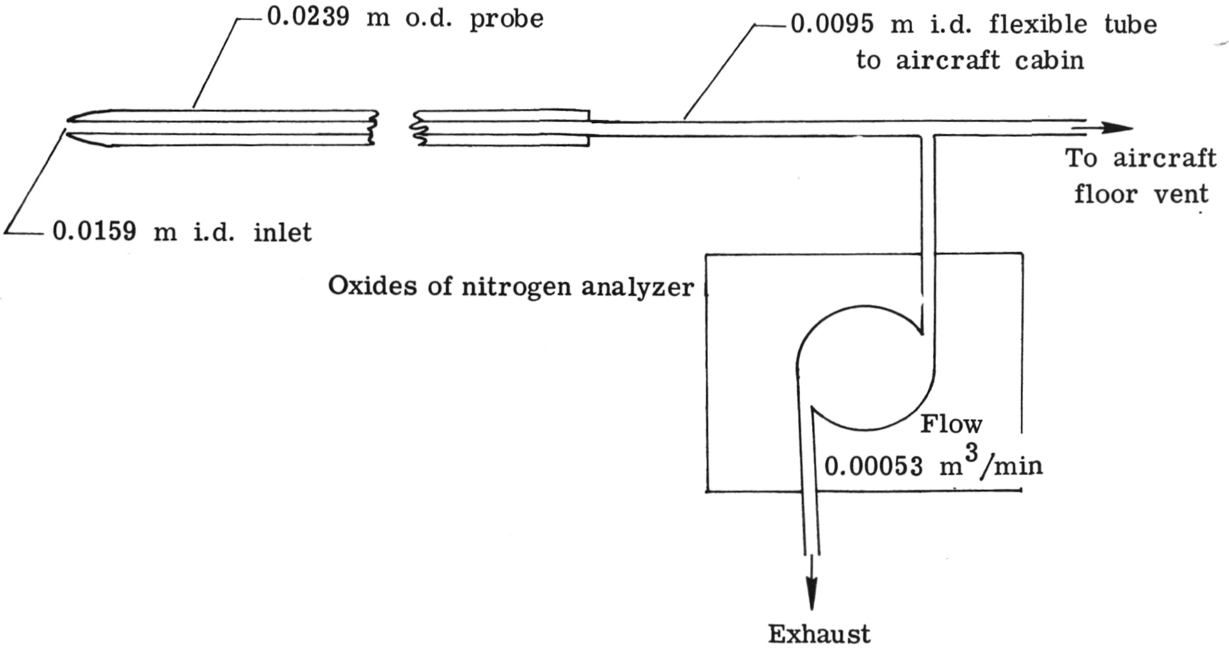

Figure 12.- Oxides of nitrogen analyzer sampling flow arrangement.

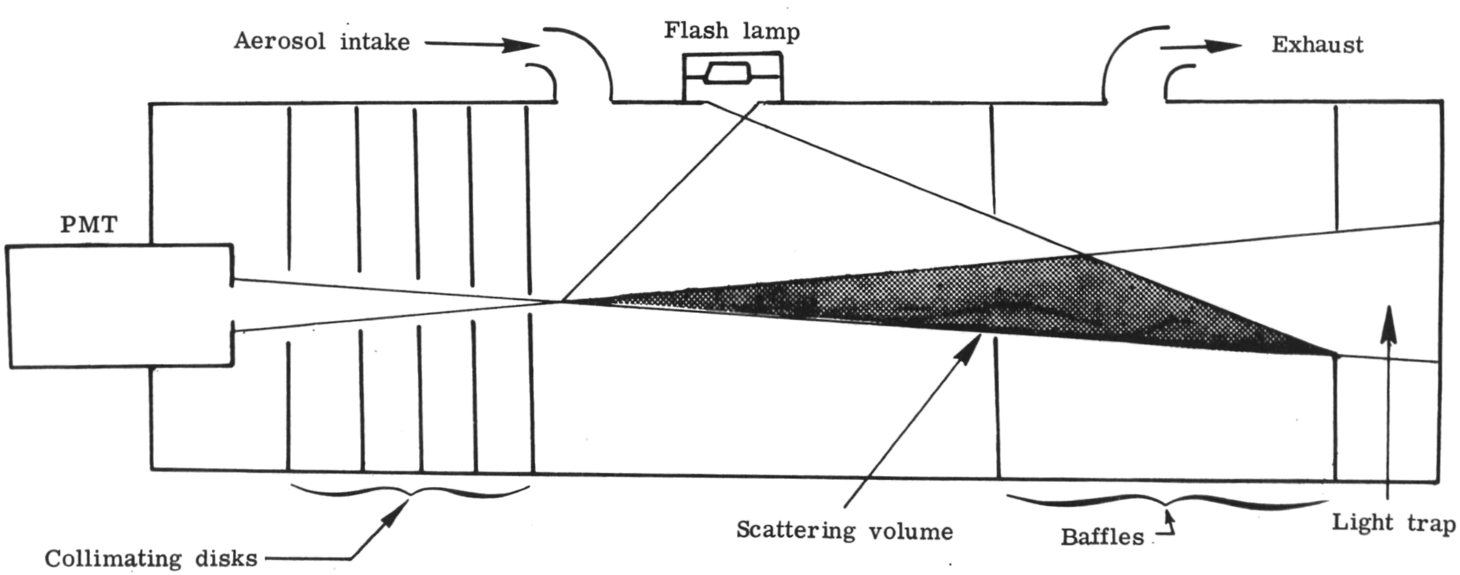

Figure 13.- A schematic diagram of integrating nephelometer.

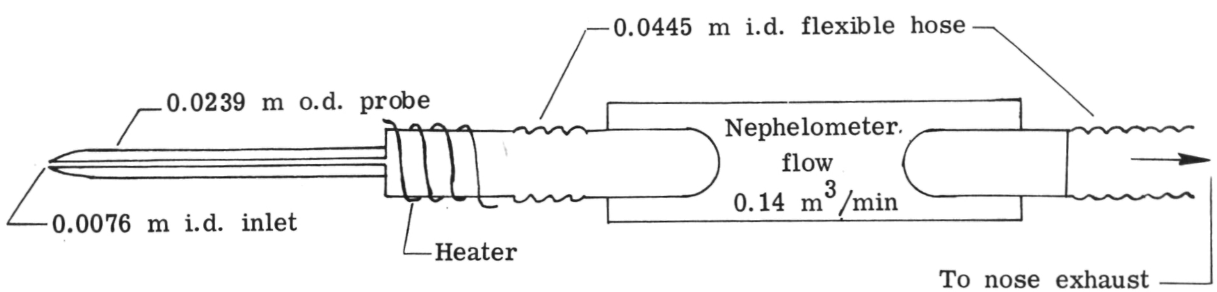

Figure 14.- Nephelometer sampling flow arrangement.

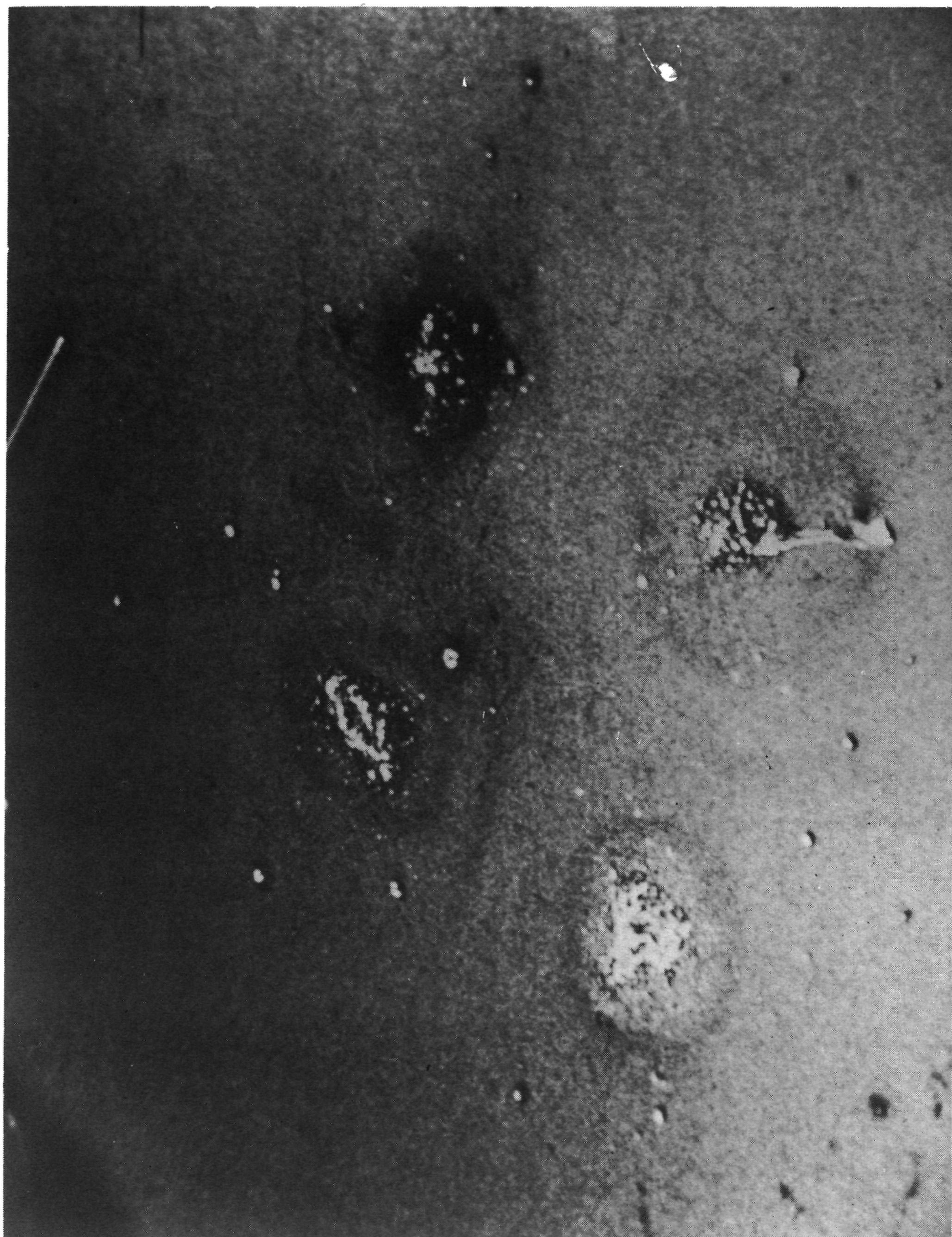

Figure 15.- Accumulation of particles on mass monitor crystal.

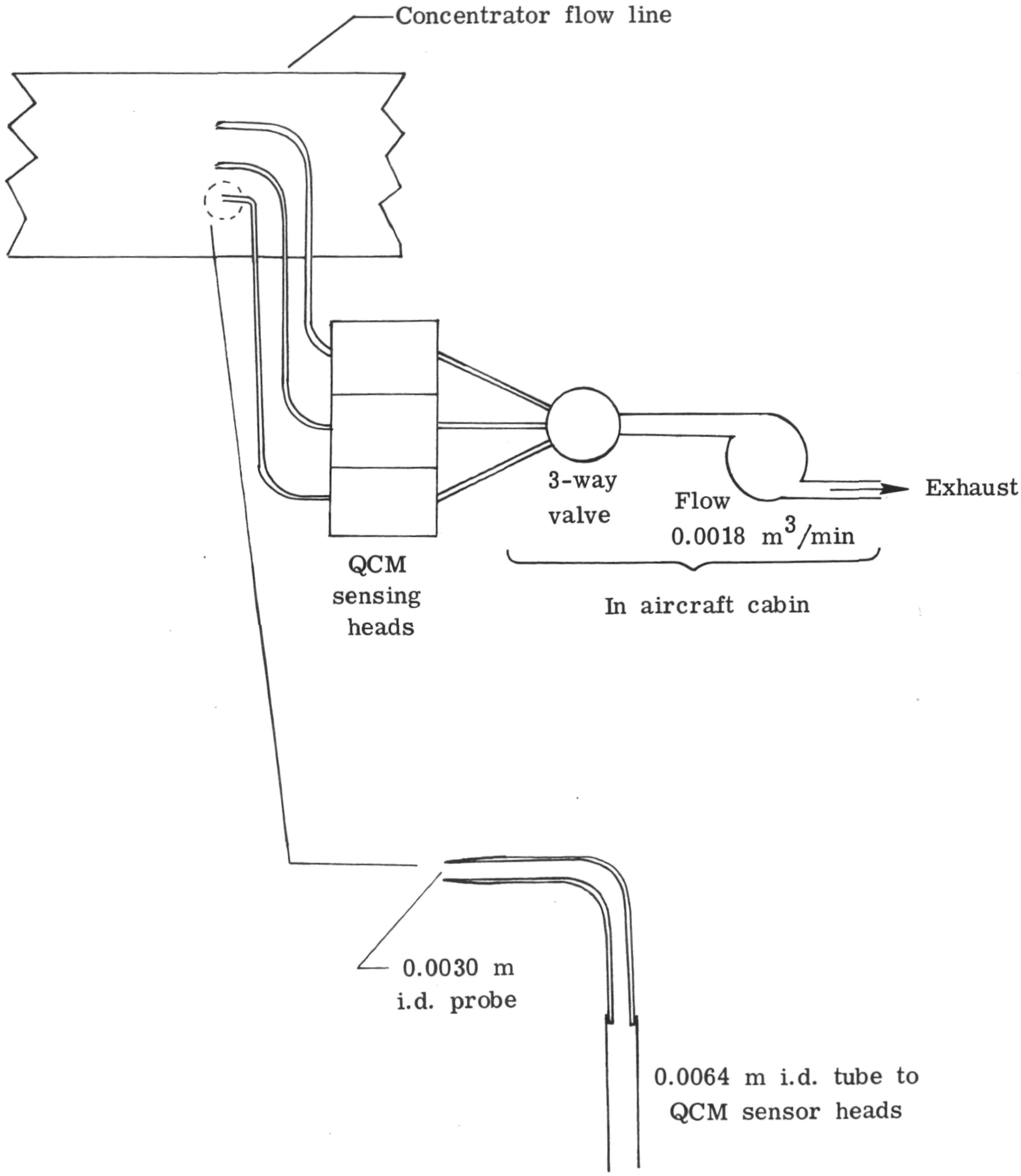

Figure 16.- QCM sampling flow arrangement.

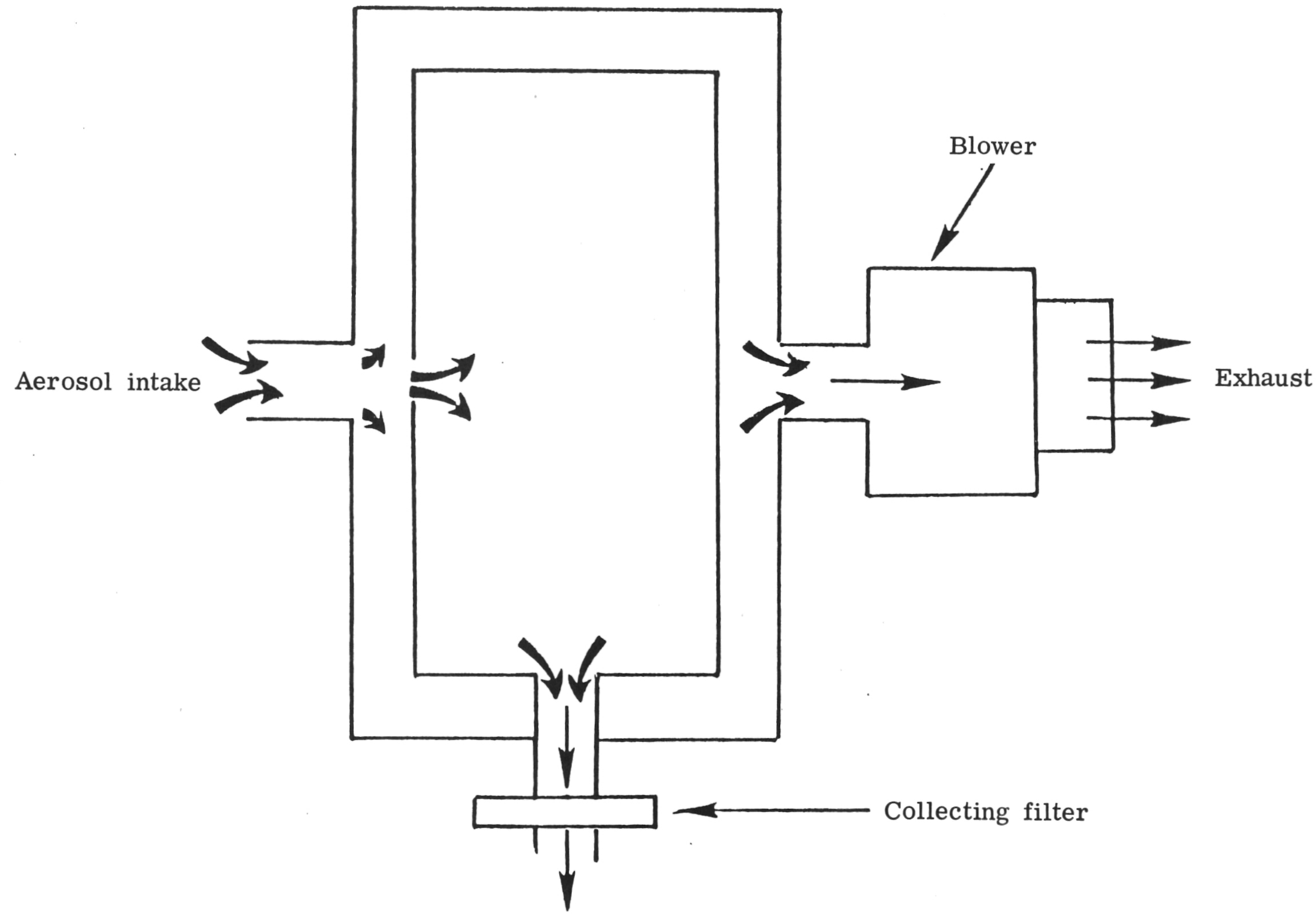

Figure 17.- Schematic diagram of NASA aerosol concentrator.

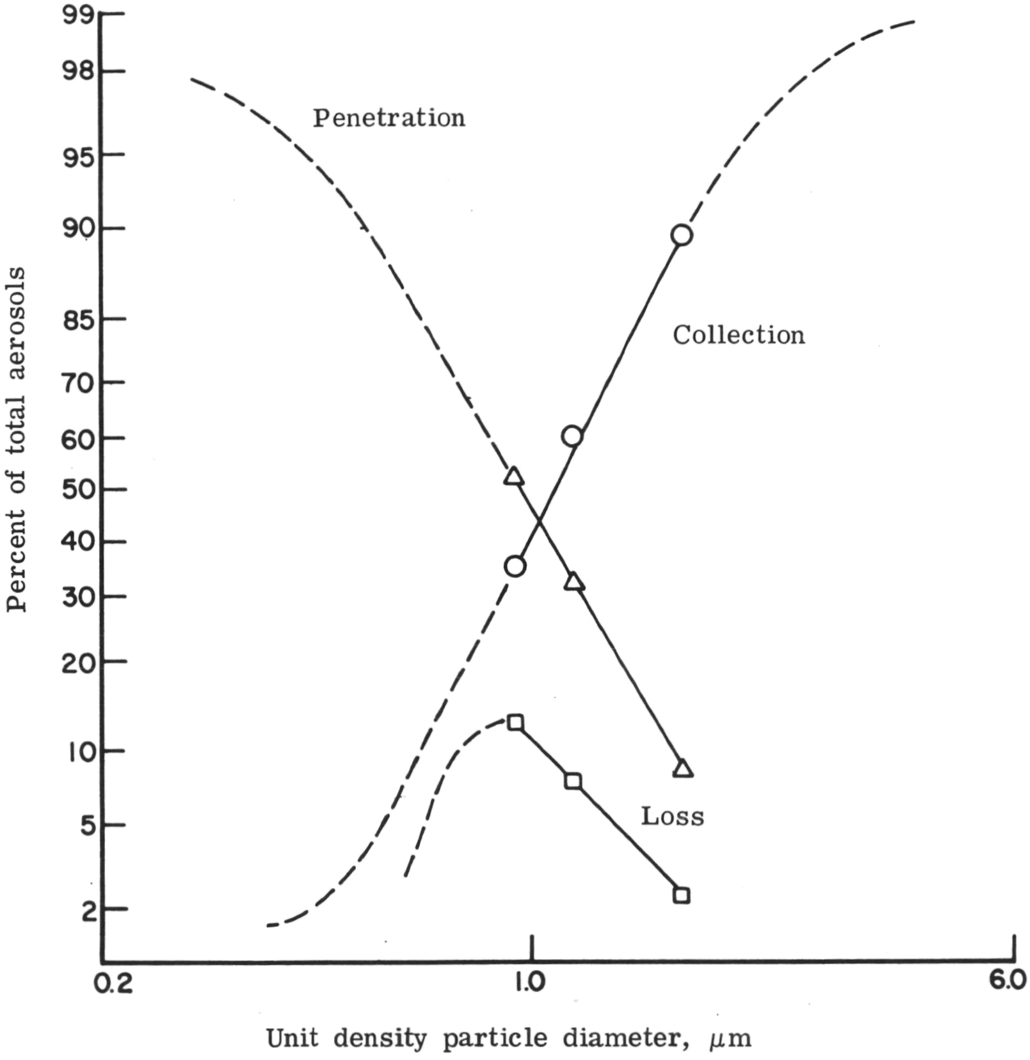

Figure 18.- Collection efficiency curve of NASA aerosol concentrator.

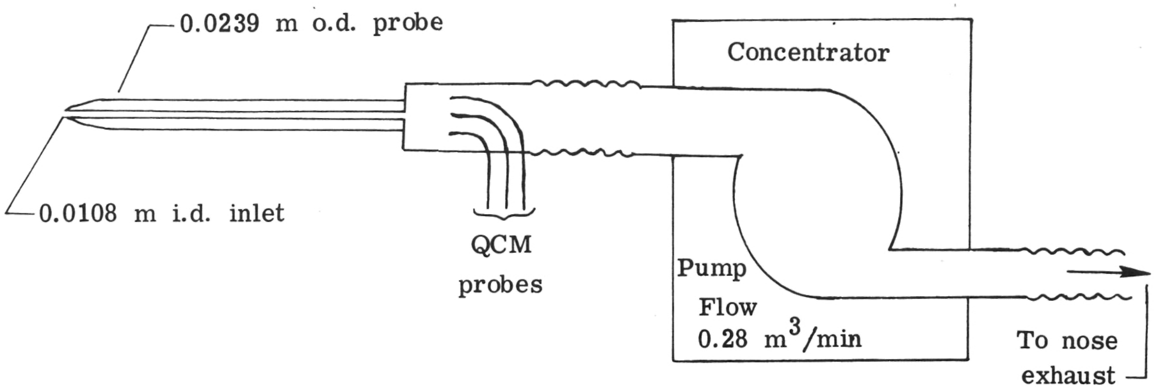

Figure 19.- Aerosol concentrator sampling flow arrangement.

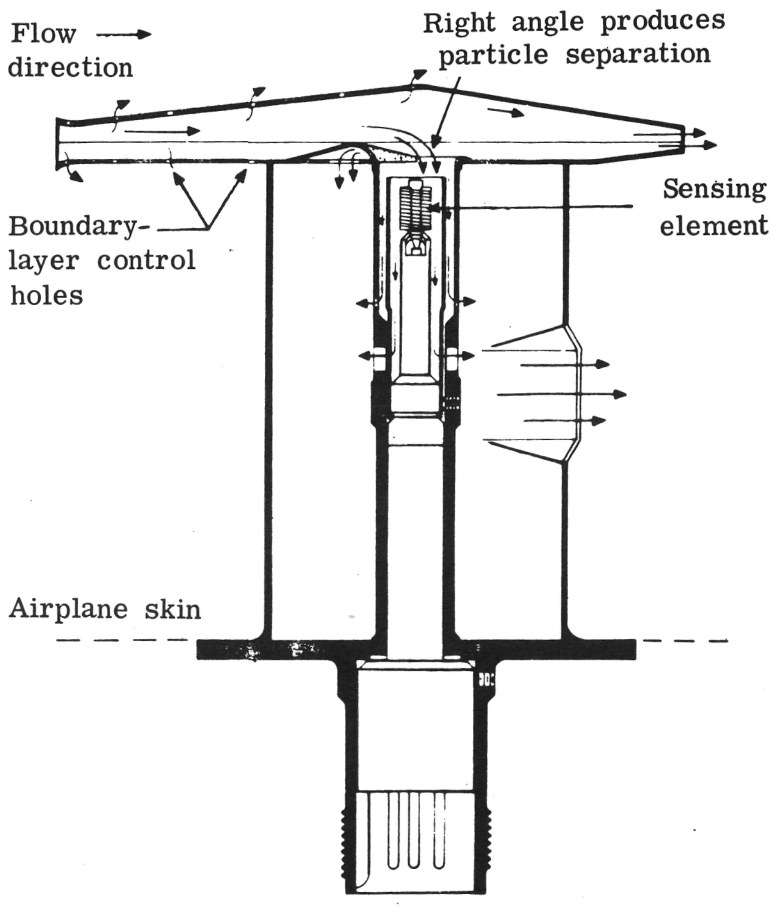

Figure 20.- Schematic diagram of total temperature probe.

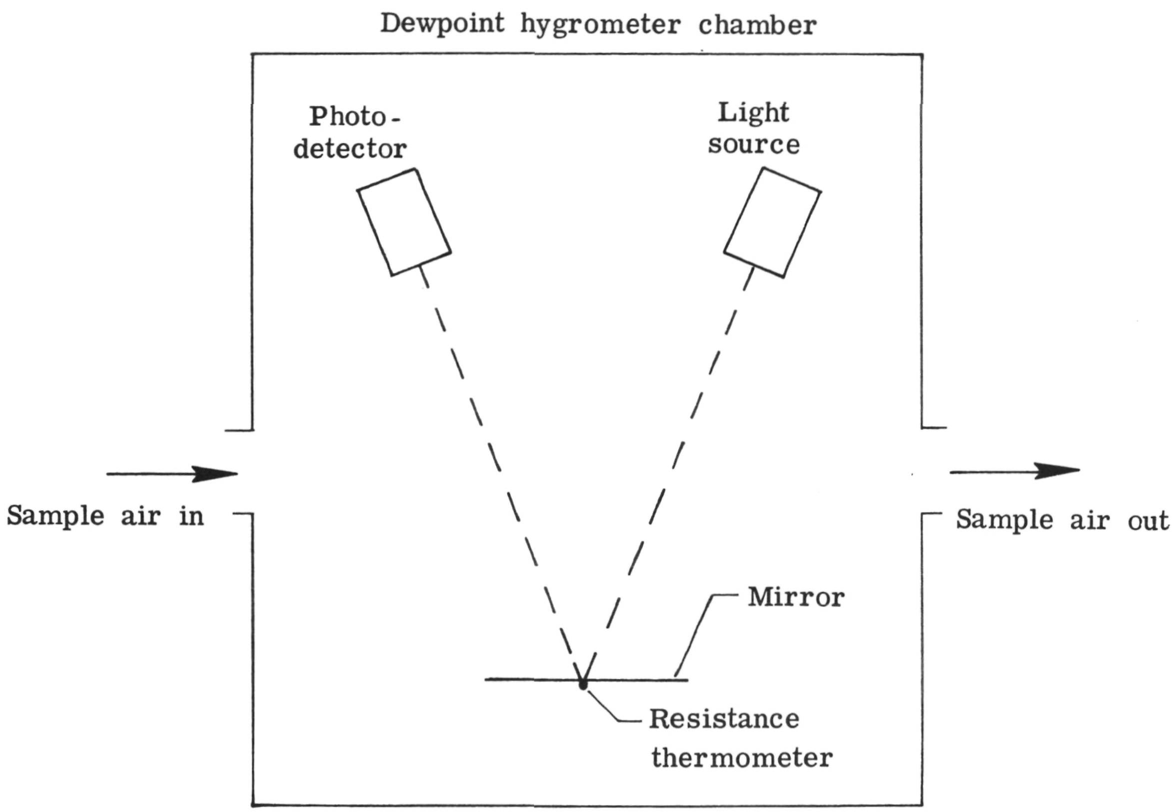

Figure 21.- Schematic diagram of dewpoint sensor.

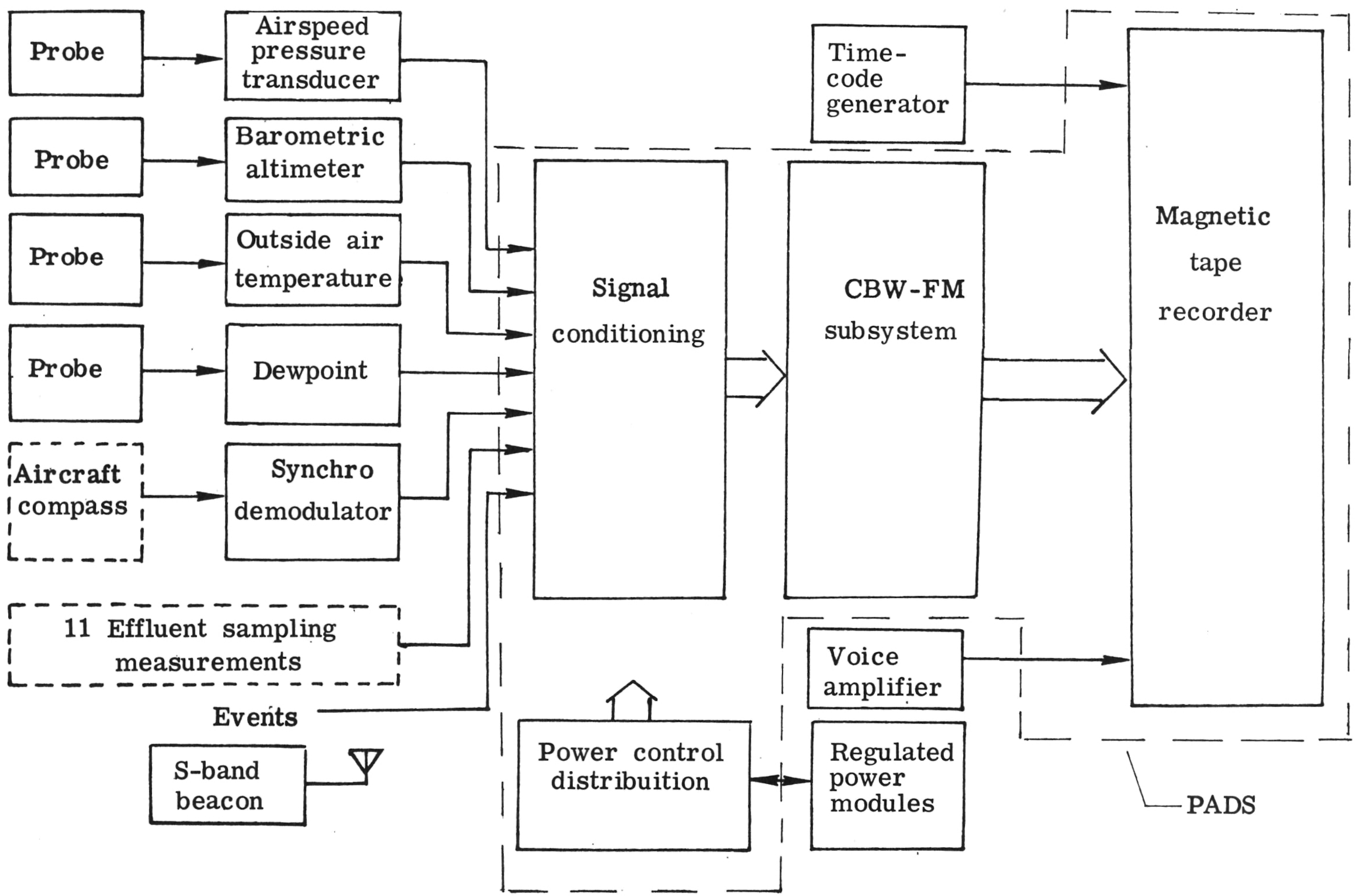

Figure 22.- Data acquisition system.

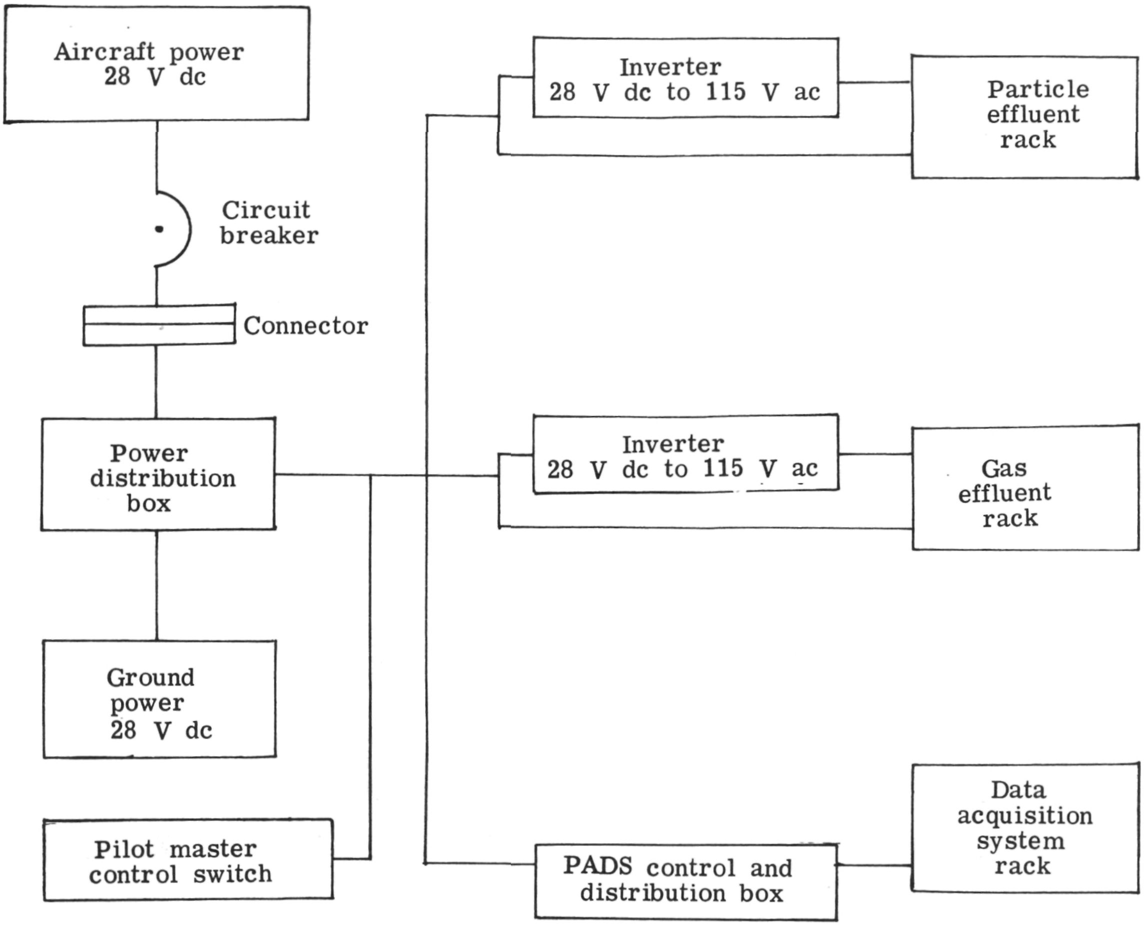

Figure 23.- Instrument power system.

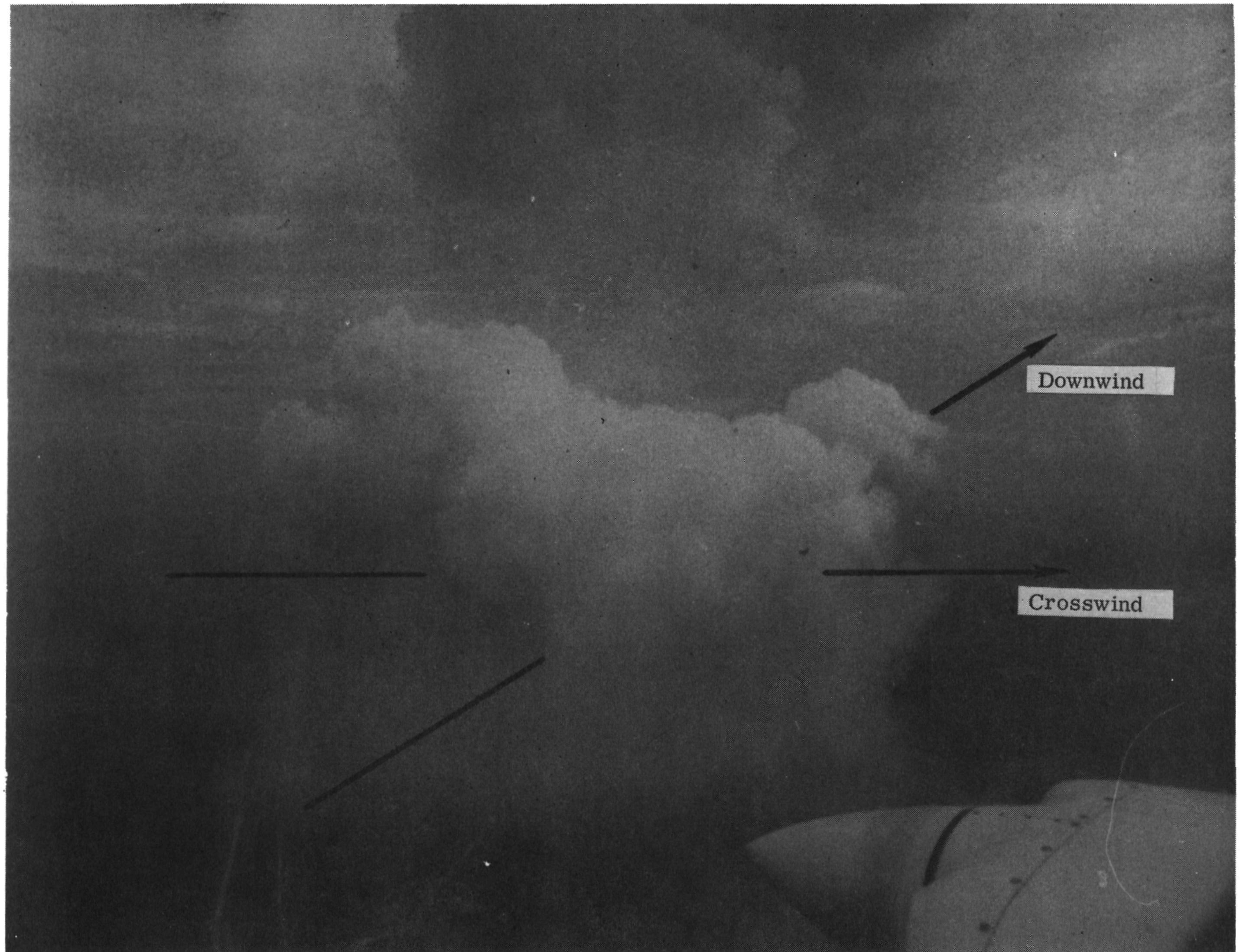

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Figure 24.- Sampling procedure.

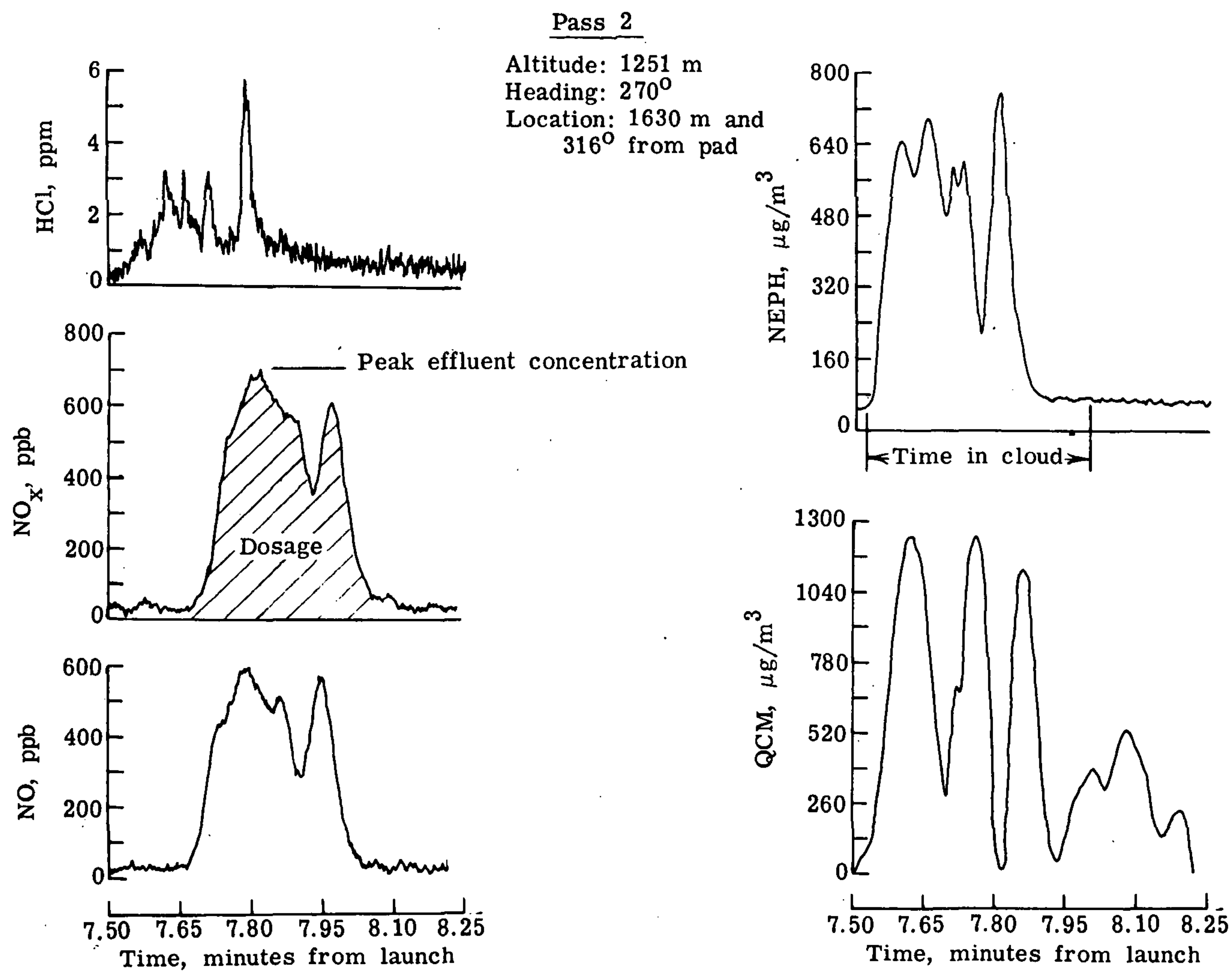

Figure 25.- Representative data from airborne sampling of Titan IIIC exhaust cloud at Eastern Test Range on August 20, 1975.

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